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Blueprint for Hydrogen Fuel Infrastructure Development

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Blueprint for Hydrogen Fuel Infrastructure Development

Introduction

This *Blueprint for Hydrogen Fuel Infrastructure Development* is based on a workshop held in October 1999. The workshop, co-sponsored by the U.S. Department of Energy (DOE), the California Air Resources Board (CARB), and the California Energy Commission (CEC), posed the question: **What has to be done, beginning *today*, to implement a hydrogen fuel infrastructure so that when hydrogen vehicles become market-ready in 3–5 years, the infrastructure needed for *on-board direct use of hydrogen* will be available?**

The workshop did not specifically address the issue of fuel choice (direct hydrogen versus on-board reforming of a liquid fuel). Although the participants acknowledged that fuel choice is an open issue, the workshop focused on near-term direct hydrogen systems with on-board hydrogen storage. This near-term focus does not preclude longer-term concerns, such as climate change and the sustainable use of resources. In fact, if this *Blueprint* is successful in addressing the near-term question, it will also help to enable optimal carbon management strategies and, eventually, result in the decoupling of energy use and environmental pollution in the transportation sector.

This *Blueprint* is based on a consensus among the workshop participants on the desirable attributes of a hydrogen fuel infrastructure, as well as on an estimate of the number, type, and uses of hydrogen vehicles anticipated in the 2000–2005 time period. This *Blueprint* also explores how addressing near-term requirements and barriers will facilitate establishment of a commercial-scale hydrogen fuel infrastructure.

Key Workshop Findings

The workshop brought together about 50 representatives of major energy, auto, industrial gas, and hydrogen production companies, as well as representatives of state and regional agencies, national laboratories, and universities.[1] The workshop participants were asked to assist DOE, CARB, and CEC by:

- Identifying specific technical and institutional barriers to implementing a hydrogen fuel infrastructure, particularly in the areas of (1) hydrogen production, distribution, dispensing, and customer interface; (2) on-board storage, vehicle systems, vehicle operations and maintenance (O&M); (3) policy, regulations, and safety
- Establishing research, development, and deployment (RD&D) needs and priorities
- Identifying the roles of federal and state government, regional authorities, industry, and other stakeholders in addressing these barriers.

The key finding of the workshop is encouraging: **there are no technical showstoppers to implementing a near-term hydrogen fuel infrastructure for direct hydrogen fuel cell vehicles.** There are, of course, engineering development needs as well as codes and standards and other institutional issues to resolve, but fundamentally the technologies required are available. Furthermore, representatives of both the energy and auto industries stated that they are technically capable of proceeding with developing both the fuel infrastructure and the vehicle technologies needed to meet near-term markets. The issue here is timing and coordination of capital investments. Given these findings, the key issue addressed in the *Blueprint* is

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[11] See Appendix A for a list of participants.

how to **facilitate a pre-competitive collaborative process for auto, energy, and government organizations to meet near-term market needs for a hydrogen fuel infrastructure.**

The workshop identified the following key requirements that will be addressed through this process:

- Prepare a government-industry roadmap that addresses all key issues, including cost, to develop a commercial-scale hydrogen fuel infrastructure.
- Establish a process (facilitated by government) for fuel providers and auto companies to initiate and grow a hydrogen fuel infrastructure.
- Provide a modular, replicable, and consistent design for a hydrogen fuel dispensing station.
- Test and certify 5,000-psi hydrogen storage containers and systems for light-duty vehicles.
- Establish a national entity to prepare, validate, and promulgate uniform codes and standards for hydrogen use as a fuel for light-duty vehicles and transit buses.
- Conduct RD&D for safety and handling of hydrogen fuel by the public.

Objective of the *Blueprint*

The objective of the *Blueprint* is to outline a 5-year action plan to develop the hydrogen fuel infrastructure needed by the 2003–2004 timeframe for both heavy-duty and light-duty vehicles. The *Blueprint* will:

- Define assumptions on the type and number of vehicles that will need hydrogen fuel in the 2000–2005 time period.
- Propose a strategy to develop a fuel infrastructure to meet near-term needs for hydrogen.
- Identify the key engineering and institutional issues that must be resolved.
- Outline and initiate a cooperative government-industry process and timetable to meet the key requirements identified above for near-term hydrogen fuel infrastructure development.

Assumptions for Hydrogen Fuel Cell Vehicles

The *Blueprint* is based on assumptions about the infrastructure that will be needed in place by 2003–2005. Because duty cycles and numbers of vehicles are significantly different, heavy-duty and light-duty vehicles are treated separately. For heavy-duty vehicles, we have assumed that most hydrogen vehicles in service by 2005 will be transit buses. In the United States today there are only three hydrogen fuel cell buses in regular operation, all of them with the Chicago Transit Authority. In the 2000–2003 time frame, one or two other transit agencies may demonstrate fuel cell buses. For example, Sunline Transit in Thousand Palms, CA, will test a prototype dbb "P4" fuel cell bus in 2000, and the California Fuel Cell Partnership plans to demonstrate five fuel cell buses in 2000–2001. The estimate of the number of transit buses that will require hydrogen by 2005 is based on a percentage of the new buses that transit agencies plan to acquire between 2000 and 2005. Data compiled by the American Public Transit Association (APTA) indicate that as of January 1, 1999, about 8,000 new transit buses were on order.[2] Of these, about 1,000 were compressed natural gas (CNG) buses. APTA reports potential orders up to 2003 totaling 14,000 buses, of which 3,400 are dedicated CNG buses. Transit agencies reporting the most potential CNG orders include Los Angeles (1,549), New York City (770), and Atlanta (210).

The *Blueprint* assumes that 5% of the CNG buses on order will be buses fueled by compressed gaseous hydrogen stored on board, as are the six fuel cell buses now in service in Chicago and Vancouver, British Columbia. Furthermore, if approximately 1,000 dedicated CNG buses are purchased nationwide each year

[2] "Natural Gas a Bigger Player in Public Transit," *First News*, Vol. 4, No. 5, Sept. 15, 1999.

between 2000 and 2005, the number of buses needing hydrogen would grow to a maximum of 50 per year by 2005. These buses will most likely be concentrated at transit agencies in urban areas where improving air quality is an important objective. Before 2005, the number of hydrogen buses will probably grow slowly, from fewer than 5 buses per year in 2000 to perhaps 40 per year in 2004.

At a recent APTA meeting, dbb fuel cell engines, inc., unveiled its latest fuel cell bus engine and announced plans to build an engine plant with a capacity of 500 engines a year, with full output expected by 2006 or 2007.[3] Given such announcements, the *Blueprint* estimates that a total of about 150 hydrogen buses will be in service by 2005 at a limited number of urban transit agencies in the United States and Canada.

The number of light-duty vehicles requiring a hydrogen fuel infrastructure is based on the California zero-emission vehicle (ZEV) and low-emission vehicle (LEV2) requirements in 2003–2005. If these requirements are fully enforced, the ZEV fleet in California will represent 10% of thetotal vehicles sold per year. Furthermore, if the number of new light-duty vehicles sold in California each year remains at about one million, about 100,000 of these new vehicles will qualify as ZEVs. With the credits and multipliers allowed under the ZEV regulation, the number of "pure ZEVs" (i.e., hydrogen fuel cell vehicles or battery electric vehicles) could be 1% of total vehicle market if manufacturers choose to meet their entire obligation using long-range battery electric vehicles or hydrogen fuel cell vehicles.[4] For the purposes of the *Blueprint*, a maximum of about 10,000 hydrogen fuel cell vehicles per year is assumed for the 2003–2005 time period.

The California ZEV regulation sets a very aggressive schedule for market-ready hydrogen fuel cell vehicles, given that only one-of-a-kind prototypes were available in late 1999. For this reason, the *Blueprint* includes both high and low scenarios for light duty hydrogen vehicles. Scenario A assumes that the maximum number of such vehicles anticipated under the California ZEV regulations will appear in the new vehicle market in 2003. In Scenario B, the *Blueprint* assumes that only a limited number (5–10) of hydrogen fuel cell vehicles will be demonstrated through projects such as the California Fuel Cell Partnership in the 2000 to 2003 time period. Hydrogen fuel required for such demonstrations can be easily provided by industrial gas companies on an ad-hoc basis. In Scenario B, the *Blueprint* assumes that in the initial years of the ZEV regulation, auto manufacturers will meet the bulk of their ZEV requirements through partial ZEV credits, such as those available to hybrid electric vehicles. The number of hydrogen fuel cell vehicles in the 2003–2005 time frame under this scenario will probably number in the hundreds rather than the thousands, let alone tens of thousands. Table 1 summarizes the number of hydrogen fuel cell vehicles assumed for the *Blueprint* under each scenario.

Although the *Blueprint* focuses on direct hydrogen fuel cell vehicles, it does not preclude considering vehicles powered by hydrogen-fueled internal combustion engines (ICE), particularly in the very near term. Such vehicles will also benefit from the development of hydrogen fuel infrastructure, and, depending on the relative availability of hydrogen-fueled fuel cell and ICE powered vehicles, *Blueprint* elements, such as dispensing station design, can be adjusted to accommodate the pace of technology development.

Table 1. Estimated Number of Hydrogen Fuel Cell Vehicles Per Year

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Transit Buses	3	7	20	30	40	50
L-D Vehicles (A)	100	500	1,000	10,000	10,000	10,000
L-D Vehicles (B)	5	10	50	100	500	1000

[3] *The Hydrogen & Fuel Cell Letter*, November 1999.
[4] Private communication with Catherine Lentz, CARB, Oct. 13, 1999.

Blueprint Strategy

Fleet Applications

In the near term, fuel cell vehicles—both heavy-duty (transit) and light-duty (cars and light trucks)—will in all probability be used in fleet applications to accommodate higher vehicle costs as well as fueling, operation, and maintenance requirements. For transit applications, hydrogen-fueled buses will begin to appear in multiple units in a few urban and very progressive transit agencies that have CNG fueling facilities and that can make the transition to hydrogen. The *Blueprint*'s strategy will focus on a limited number of transit agencies to develop hydrogen fueling facilities that can be expanded later to serve additional buses as well as light-duty fleet and non-fleet vehicles.

For light-duty vehicles, a key element of the *Blueprint*'s strategy will be to build on the ZEV regulation and mandates in California and those anticipated in New York and Massachusetts. Another key element will be to link the *Blueprint* with on-going hydrogen fuel infrastructure development efforts, such as those by the California Fuel Cell Partnership and by the DOE to install a hydrogen fueling station in Las Vegas, Nevada.

The strategy will also include linkage of ZEV mandates with other complementary mandates and regulations. One example will be to link ZEV mandates with alternative fuel vehicle (AFV) fleets mandated under the federal Energy Policy Act (EPAct) and encouraged under the Clean Cities Program. The Federal AFV User Program may also provide opportunities for linkage in the near term.EPAct (Public Law 102-486) was enacted in 1992 to accelerate the use of alternative fuels in the transportation sector. Under EPAct, DOE's primary goals are to decrease the nation's dependence on foreign oil and to increase energy security through the use of domestically produced alternative fuels. DOE's overall mission is to replace 10% of petroleum-based motor fuels by the year 2000 and 30% by the year 2010. EPAct also mandates federal, state, and alternative fuel provider fleets to purchase AFVs. Federal fleets must follow guidelines established in Executive Order 12844 (April 21, 1993) and subsequently reinforced by Executive Order 13031 (December 13, 1996).

Clean Cities is a DOE-sponsored program designed to encourage the use of AFVs and the installation of supporting infrastructure throughout the nation. Approximately 70 cities have received designation as Clean Cities. Stakeholders in the program pledge to make AFV acquisitions through the year 2005, and the Clean Cities Program is working to transform these pledges into firm vehicle purchases or conversion orders, concurrent with challenging manufacturers to develop product lines that meet the various needs of the market. The partnerships fostered through Clean Cities also have led to the expansion of the alternative fuel infrastructure. Program members are encouraged to establish links to create regional alternative fuels infrastructure. The Clean Cities Program also enables DOE to provide assistance to federal, state, and local fuel supplier fleets required by EPAct to make AFV acquisitions or conversions.

The Federal AFV User Program is designed to support alternative fuel infrastructure development by focusing federal AFV placement in a small number of cities. Based on a number of ranking factors, including number and concentration of federal vehicles and local support, DOE chose six cities: Albuquerque, NM; Denver, CO; Melbourne/Titusville/Kennedy Space Center, FL; Minneapolis/St. Paul, MN; Salt Lake City, UT; and the San Francisco Bay Area, CA.

The *Blueprint* is also open to the possibility of enacting a federal ZEV mandate to augment existing AFV mandates. Such a mandate will accelerate hydrogen infrastructure development and would complement efforts by agencies, such as the National Park Service, to reduce the impact of visitors some to the nation's most environmentally sensitive areas.

Hydrogen Production with On-Site Storage and Dispensing

Hydrogen Production Options

For a very small number of buses, transit agencies will most likely follow the Chicago Transit Authority model, where liquid hydrogen made at a large centralized plant is trucked to and stored at a fueling facility at or near the transit agency's service yard. The liquid hydrogen is pumped and vaporized for storage on the bus. As an alternative, transit companies could follow the British Columbia Transit (Vancouver) model of on-site electrolysis. Storage tanks on the bus are filled overnight as the hydrogen is generated. A third possibility is on-site generation of hydrogen using a small-scale reformer. For the *Blueprint*, three production options will be considered:

- Off-site steam methane reforming of natural gas with tanker-truck delivery of liquid hydrogen to the refueling station with on-site storage of liquid and gaseous hydrogen
- On-site electrolysis with on-site storage of gaseous hydrogen
- On-site natural gas reforming with on-site storage of gaseous hydrogen.

Production options should be designed so that they can be scaled and mixed as needed to meet different demands at specific sites.

Process to Facilitate Interaction between Fuel Providers and Auto Companies

The *Blueprint* includes a process facilitated by government to continue the interaction between fuel providers and auto companies fostered at the workshop. This interaction will help the two principal industrial entities to work closely together so that the near-term hydrogen fuel infrastructure can grow and meet long-term needs.

Dispensing Station Design

A standardized, modular design for a hydrogen dispensing station is essential both to meet near-term needs and to facilitate and sustain long-term fuel infrastructure development. The hydrogen supply could be obtained from any of the three production options described above, including combinations of the options. The dispensing station will be modular in design so that liquid hydrogen and gaseous hydrogen for both compressed and hydride storage can be accommodated as needs arise. An important first step will be to standardize key components for hydrogen fueling facilities planned by the California Fuel Cell Partnership and by the DOE in Las Vegas.

On-Board Hydrogen Storage

The major effort under the *Blueprint* for on-board hydrogen storage will be to test and certify hydrogen storage containers and systems for light-duty vehicles. Hydrogen stored as a compressed gas at 5,000 psi, as a liquid, and as a hydride will be included in this effort.

Hydrogen Codes and Standards and Safety

Workshop participants assigned a high priority to hydrogen safety, along with the accompanying codes and standards. Attendees recommended that DOE, the Department of Transportation (DOT), and other appropriate federal agencies establish a national entity to prepare and promulgate uniform codes and standards for hydrogen use as a fuel for light-duty vehicles and transit buses. A number of efforts are under way through the International Standards Organization's (ISO) Technical Committee (TC197). Table 2 shows the status of the efforts being carried out under ISO/TC197.

DOE has supported the preparation of several of these standards, which are in progress through the National Hydrogen Association. DOE will continue to support development of standards and is also supporting a comprehensive effort to incorporate codes for hydrogen applications through the International Code Council (ICC) process. Work on codes and standards will also be coordinated with hydrogen codes and standards activities sponsored by the European Union.

In addition to codes and standards, the workshop recommended RD&D on public safety and handling of hydrogen fuel. Such RD&D will be incorporated in the development, testing, and demonstration of hydrogen fueling facilities in fleet applications and as part of training for fleet operators and personnel. This work will be coordinated with the European Integrated Hydrogen Project.

Government-Industry Roadmap for a Commercial-Scale Hydrogen Fuel Infrastructure

The recommendation for a collaborative effort between government and industry to develop a roadmap for a commercial-scale hydrogen fuel infrastructure is perhaps the key result of the workshop. The workshop and this draft *Blueprint* are the first steps in assembling such a collaborative effort. In effect, the *Blueprint* outlines in brief the first 5 years of a more detailed roadmap for hydrogen fuel infrastructure development.

Table 2. Status of ISO/TC197 Standards

Identification Number	**Title**	**Working Group**	**Convener (Country)**
*DIS 13984	Liquid H_2 - Land Vehicle Fueling System Interface	WG 1	SCC (Canada)
*DIS 14687	H_2 Fuel-Product Specification	WG 3	ANSI (USA)
**NP 15594	Airport H_2 Fueling Facility	WG 4	DIN (Germany)
**NP 15866	Gaseous H_2 and H_2 Blends--Vehicular Fuel Systems	WG 5	ANSI (USA)
**NP 15869	Gaseous H_2 - Vehicle Fuel Tanks	WG 6	ANSI (United States)
**NP 15916	Basic Requirements for Safety of H_2 Systems	WG 7	DIN (Germany)
***WD 13985	Liquid H_2 - Land Vehicle Fuel Tank		SCC (Canada)
***WD 13986	Tank Containers for multimodal Transport of Liquid H_2		SCC (Canada)

*Draft International Standards (inquiry stage--draft being studied by all ISO member bodies; on verge of becoming an International Standard)
**New Proposal (approved work item--1st draft not available)
***Working Draft (preparatory stage--draft under study at the working group level)

Action Plan

The Action Plan attempts to align the findings and recommendations of the workshop, along with the strategy described above, into a 5-year agenda to develop a hydrogen fuel infrastructure that meets the needs of both transit and light-duty direct hydrogen fuel cell vehicles by 2005. The Action Plan also attempts to establish the foundation for a commercial-scale fuel infrastructure that can be developed as needed to meet future market requirements. DOE has formed a Core Team of representatives from the organizations that participated in the workshop. This Core Team will be asked to endorse the *Blueprint* and guide a collaborative government-industry effort to implement the tasks and schedule proposed in Table 3. The first job of the Core Team will be to develop detailed work plans for each task in the Action Plan.

Members of the Core Team are:

- Ed Danieli, Praxair, Inc.
- Ken Koyama, California Energy Commission
- Mujeeb Ijaz, Ford Motor Company
- Raj Rajagopalan, Shell Hydrogen
- Andrew Stuart, Stuart Energy Systems.

Technical support to the Core Team will be provided by Jay Keller of Sandia National Laboratory and Jim Ohi of the National Renewable Energy Laboratory, and overall program management will be provided by *ex officio* members of the Core Team, Sig Gronich and Neil Rossmeissl of the DOE Hydrogen Program.

Next Steps

The *Blueprint* and proposed Action Plan was reviewed by all workshop participants, and their comments have been incorporated in this revised *Blueprint* and Action Plan. This document will be posted on the DOE Hydrogen Web site (www.eren.doe.gov/hydrogen) for additional review and comment. The *Blueprint* and Action Plan will be periodically revised, particularly if significant comments are received.

Acknowledgments

The DOE Hydrogen Program thanks all of the participants and the organizations they represented at the workshop. The DOE also thanks the CARB and the CEC for co-sponsoring the workshop and for working with DOE to prepare the *Blueprint* and Action Plan.

Table 3. Schedule of Tasks for the *Blueprint*

Task	**Year**					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**
Standardized Dispensing Station Design	Establish requirements, draft/validate design, standardize dispensers and other key components	Adopt and promulgate design	Install initial dispensing stations	Original equipment manufacturers (OEMs) build standard dispensing equipment	Build dispensing stations as needed	Build dispensing stations as needed
Test and Certify Hydrogen Containers	Adopt test requirements, conduct testing, certify to DOT standards	Validate container systems on vehicles, begin fleet testing	Define O&M requirements; OEMs begin building containers to certified standards	OEMs build containers to certified standards	OEMs build containers to certified standards	OEMs build containers to certified standards
Integrated Codes and Standards (C&S)	Prepare overall C&S strategy	Submit draft code to ICC	ICC publishes code	Effective date of code	Prepare revision if needed	Submit revisions to ICC
Safety RD&D for Public Use of H_2	Prepare and initiate RD&D Plan	Conduct RD&D, training	Conduct RD&D, training	Publish safety and training guidelines	Validate public refueling safety	Start limited public refueling
Roadmap	Core group prepares and adopts Roadmap	Begin to implement Roadmap	Revise Roadmap for longer term	Install initial infrastructure	Validate fleet vehicle refueling	Revise Roadmap

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13. ABSTRACT *(Maximum 200 words)* This *Blueprint* is based on a workshop held in October 1999. The workshop posed the question: What has to be done, beginning *today,* to implement a hydrogen fuel infrastructure so that when hydrogen vehicles become market-ready in 3–5 years, the infrastructure needed for on-board direct use of hydrogen will be available? Although the participants acknowledged that fuel choice (direct hydrogen versus on-board reforming of a liquid fuel) is an open issue, the workshop focused on near-term direct hydrogen systems with on-board hydrogen storage. This near-term focus does not preclude longer term concerns, such as climate change and the sustainable use of resources. If this *Blueprint* is successful in addressing the near-term question, it will also help to enable optimal carbon management strategies and, eventually, result in the decoupling of energy use and environmental pollution in the transportation sector.

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